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PRESS-LAM:

PROGRESS IN TECHNICAL DEVELOPMENT OF LAMINATED VENEER STRUCTURAL PRODUCTS

USDA FOREST SERVICE
RESEARCH PAPER
FPL 279
1977

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
MADISON, WIS.

ABSTRACT

Press-Lam promised to provide a quality structural wood product that can be rapidly produced, at higher than conventional yields and for competitive costs.

A key to the rapid processing is in fast-drying rotary-cut veneer and laminating the still-hot plies into a continuous sheet. The sheets of Press-Lam material can be combined in different ways to produce a variety of products--such as being vertically laminated for structural beams. Randomization of characteristics in the plies can result in a product of greater uniformity than comparable high-volume solid-sawn lumber, while possibly improving strength and stiffness.

This report expands previous work with southern pine to involve Douglas-fir. Basic results continue to show a yield of structural product to be well over 50 percent.

Predicting the strength of Press-Lam by using stiffness values appeared promising.

Structural grade timbers can be produced by cutting low-grade logs to make Press-Lam that is laminated to the desired size. Panels produced in a similar fashion can meet specifications of panels for timber bridges. Treatability of the material was excellent and easily controlled. Fire resistance compared favorably with solid wood.

Critical in providing Press-Lam at reasonable cost is the high production rate achieved with a continuous cold clamping machine.

Various means of providing processing flexibility proved acceptable. These included reheating previously dried veneer, drying veneer with jet or roller veneer dryers instead of press drying, increasing the temperature of drying, and incorporating finger joints into the material.

CONTENTS

FOREWORD

This publication summarizes the progress of a U.S. Forest Products Laboratory research team in estimating the technical and economic potential of producing a laminated structural product by a log to product system.

Team members collectively defined the anticipated problems and sought practical solutions. Individual team members, and their contributions to this effort were:

E. L. SCHAFFER, Engineer--team leader, warp tendency, fire resistance, economic analysis

R. W. JOKERST, Forest Products Technologist--adhesives, bond quality, laminating

R. C. MOODY, Engineer--laminated material strength properties, structural performance

C. C. PETERS, Engineer--rotary cutting, log yield

J. L. TSCHERNITZ, Chemical Engineer--drying, processing concepts, economic analysis, preservation

J. J. ZAHN, Engineer--structural performance

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PRESS-LAM: PROGRESS IN TECHNICAL DEVELOPMENT OF LAMINATED VENEER STRUCTURAL PRODUCTS

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By

FPL Press-Lam Research Team[1]

Forest Products Laboratory,[2] Forest Service

U.S. Department of Agriculture

INTRODUCTION

The U.S. Forest Products Laboratory is continually seeking to provide technology for more efficient use of the wood resource, without increasing environmental pollution and energy demands. One of these research activities has centered on a processing system to produce a structural material, called "Press-Lam", that is suitable for such items as beams and other structural members (fig. 1) (*7, 12, 19, 22*).[3]

Press-Lam promises an improvement in yield of dry product from logs, as compared to sawing, in log-to-product times of less than 1 hour. The key to the speedy processing is the saving attained by press drying rotary-cut veneer up to 1/2 inch (in.) thick, and laminating the still hot plies into a continuous sheet. (One concept of a processing system is shown in fig. 2.) p. 15

[1] *Team members were:* R. W. Jokerst, Wood Technologist; R. C. Moody, Engineer; C. C. Peters, Mechanical Engineer; E. L. Schaffer, Engineer-Team Leader; J. L. Tschernitz, Chemical Engineer; and J. J. Zahn, Engineer.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] *Italicized numbers in parentheses refer to literature cited at the end of report.*

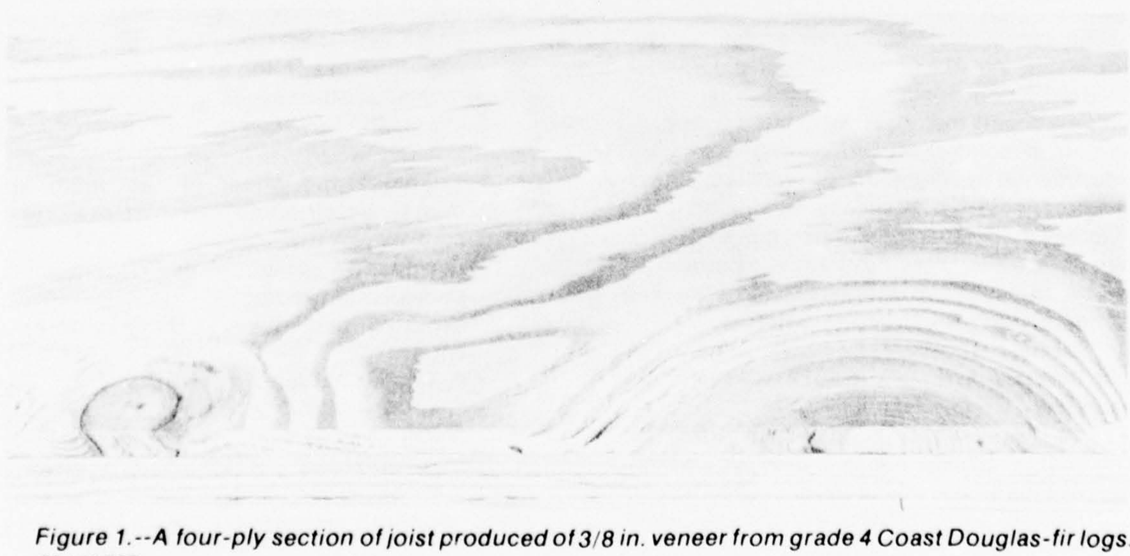

Figure 1.--A four-ply section of joist produced of 3/8 in. veneer from grade 4 Coast Douglas-fir logs.
(M 144 667)

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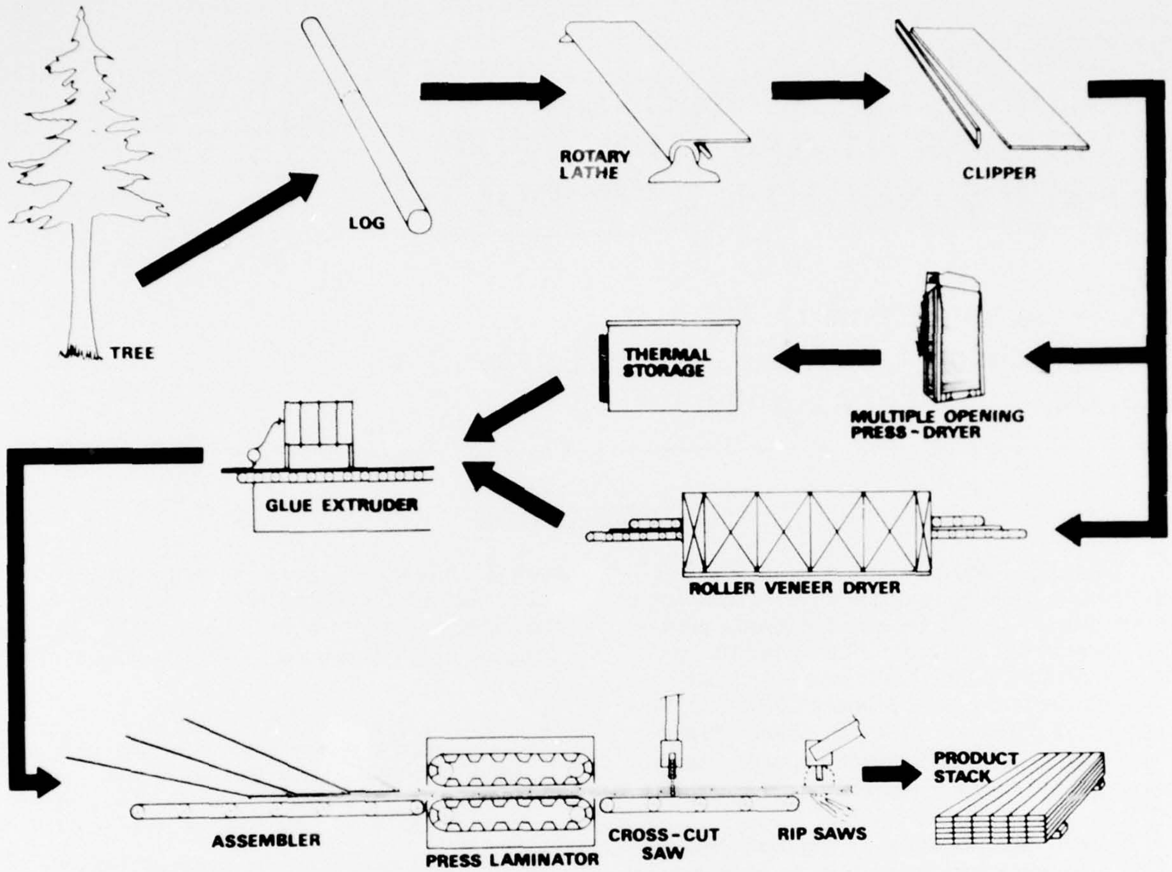

Figure 2.--Concept of a Press-Lam processing system incorporating multiple-opening press dryer or roller veneer dryer.

(M 140 956)

An approximate economic analysis of the processing in 1972 (*7, 22, 23*) had shown that the production costs were reasonable when compared with the costs associated with production of solid-sawn lumber. Moreover, an experimental evaluation of the structural performance of a vertically laminated joist indicates that the material will be more uniform than solid-sawn, may have superior strength, and be equivalent in stiffness to large-market volume solid-sawn structural lumber.

Our past reports (*7, 12 19, 22*) largely discuss the results of work to 1972 on Press-Lam made from southern pine.

In 1972, work was initiated to reinforce the technical feasibility for and improved economy of Press-Lam production. It specifically:

--sought an improved dry product yield estimate

--employed Coast Douglas-fir or southern pine logs of varying grades

--looked at alternatives in processing

--searched for lower cost compatible adhesives

--estimated the effect of raw material quality on structural product performance

--developed a potential method for quality control and grading

--explored mechanical fastener performance

--estimated tendency to warp

--examined technical potential and treatability of large sections

Some of these points are considered further in this report, and recommendations made for future research and development.

IMPROVED YIELD

Rotary cutting of veneer in suitable thicknesses continues to be feasible from bolts up to 8 feet (ft) long. Southern pine bolts 8 ft long had been previously rotary cut to produce industrial veneer thicknesses of 1/2 in. (*7, 20*). Similarly, 8-ft hardwood bolts were cut industrially into 3/8-in. veneer. At FPL, rotary cutting 4-ft bolts of both Coast Douglas-fir and southern pine in suitable thicknesses continues to be sucessful.

Green veneer yields for 4-ft bolts rotary cut at FPL to 8-in.-diameter cores are shown in figure 3. An average green veneer yield of 68

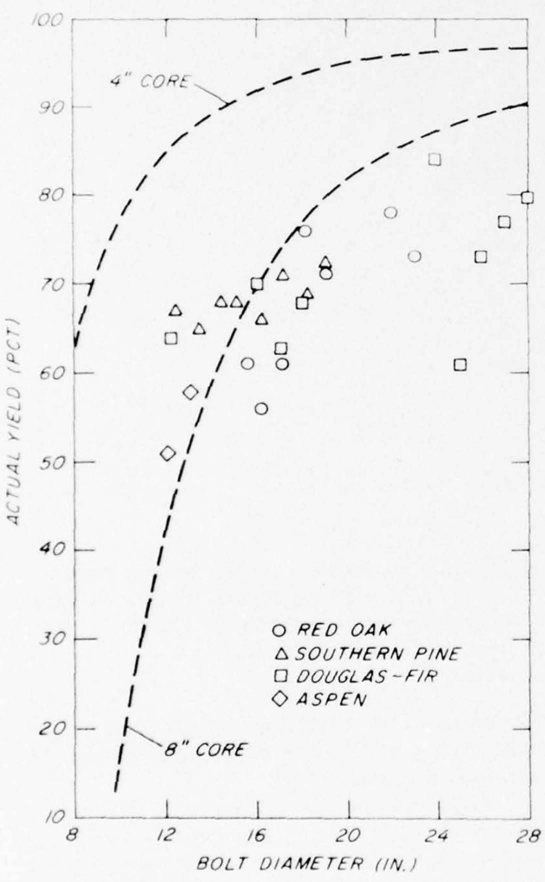

Figure 3.--Theoretical yields (curves) and actual yields (points) of veneer from four species cut at thicknesses from 0.270 to 0.500 inch (20). Average actual core diameters were 7.7 in., compared to the theoretical 4- and 8-in. cores.

(M 144 643)

percent (pct) of the bolt cylindrical volume can be attained on 12- to 28-in. bolts. Bolts of diameters from 12 to 20 in. yielded an average of 65.5 pct, and bolts of 20- to 28-in. diameter yielded an average of 75 pct. Peeling Coast Douglas-fir blocks down to 4-in. cores and producing veneer about 1/4-in. thick should increase yield another 10 pct on these diameters.

Conversion of green veneer volumetric yield to dry product yield can be simply estimated by deducting drying shrinkage and trim losses from product dimensions. Shrinkage loss during press drying at a platen pressure of 50 pounds per square inch ($lb/in.^2$) is 7 pct radially for Coast Douglas-fir and 9 pct radially for southern pine. Trim losses are about 2 pct on 7-1/2-in.-wide Press-Lam. Hence, when rotary cutting Coast Douglas-fir logs (20- to 28-in. diameter) to 8-in. cores, dry Press-Lam average volumetric yields should be about 66 pct, and approaching 75 pct when rotary cutting to 4-in. cores. This is consistent with dry product yield estimates of 60 pct or more reported previously for either Douglas-fir or southern pine logs by the Press-Lam Team (*7*), Bohlen (*4*), and Koch (*13*).

Measured yields of dry veneer going into plywood products have been much lower. Data for Coast Douglas-fir (table 1) show that plywood veneer yield is about 55 pct for 75 bolts from 22 to 40 in. in diameter (to cores of 6.5 in.) (*8*). The sum total of panel trim loss (av. of 8.5 pct), compression and sanding (6.1 pct), and shrinkage (6.7 pct) is 21.3 pct. In Press-Lam processing, the estimated panel trim loss is reduced to 2 pct, and the combined press-dried Douglas-fir veneer compression and shrinkage is about 7 pct. These losses total 9 pct.

Addition of the 12.3 pct difference (between plywood and Press-Lam processing losses) to the 55 pct average plywood yield indicates that a 67 pct dry product yield can be achieved for Press-Lam on these log and core diameters. This is remarkably close to 66 pct obtained experimentally at FPL.

Harpole (*10*) employs similar adjustments to the extensive Douglas-fir lumber and veneer yield information of Lane *et al.* (*14, 15*) to obtain Press-Lam yield estimate ranges and how they might compare with plywood and

lumber from the same logs (table 2). The anticipated yield is close to that predicted above for both special peeler and No. 2 sawmill logs (*10*). The lower grade No. 3 sawmill logs result in 8 pct lower yields for plywood and Press-Lam.

All of the yield data obtained thus far, or calculated from other references, is encouraging. But a large-scale Press-Lam processing yield study is needed to substantiate these promising results.

PROCESSING ALTERNATIVES

In order to improve processing flexibility, yet retain the rapid stored-heat cure of laminated veneer, other methods of drying the veneer, reheating the cold veneer, and inclusion of an improved end joint (finger joint) were explored.

Methods of drying

The rates of drying, and changes in veneer characteristics, were compared for three methods--press-drying, jet drying,[4] and roller drying. Figure 4 illustrates the difference between each method for two thicknesses of veneer dried at 300° F. Press-drying was about twice as fast as jet or roller veneer drying to a given moisture content (leading to considerations such as shown in fig. 5). In addition, the drying rate for a jet dryer is about 10 pct faster than a roller dryer for veneer between 1/4 and 1/2 in. thick.

The rate of drying may be increased by increasing the dryer operating temperature in both press- and jet dryers. Coast Douglas-fir veneer darkened with an increase in temperature above 300° F, the degree of which was proportional to the temperature and duration of heating.

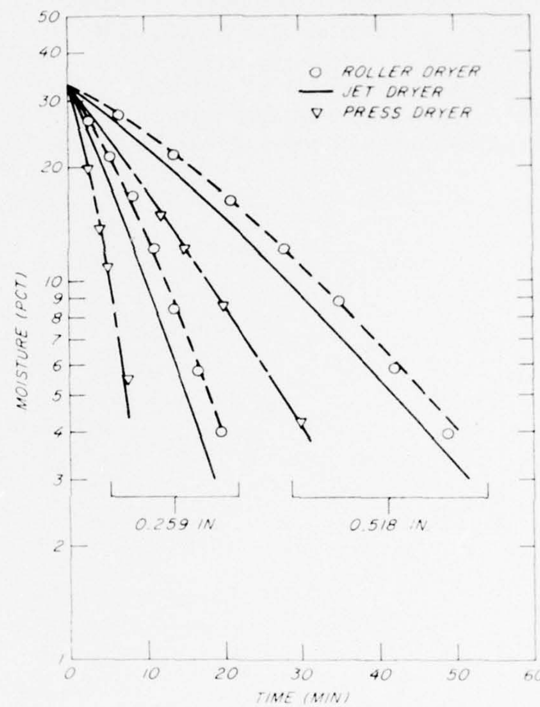

Figure 4.--Comparison of the drying time at 300° F for three types of dryers and Douglas-fir (heartwood) veneer thicknesses of 0.259 and 0.518 in.

(M 144 644)

Bond quality and drying-reheating

Though veneer can be dried rapidly at high temperatures, could such dried veneer be adequately laminated after drying or upon reheating? To enhance processing flexibility, this point was studied.

As an alternative to a press dryer, a roller veneer dryer appeared acceptable, based upon equivalent strength of bonds produced and wood failure observed. When Douglas-fir veneer was reheated after it had been dried to less than 20 pct and cooled, acceptable bonds were achieved regardless of method of drying or method of reheating used. The probability of poor bond quality increased for veneer at 20 pct average moisture content and above. How drying or reheating method affects bond strength is shown in table 3.

In general, press-drying veneer at temperatures to 500° F and laminating, using the stored heat of drying to cure the resin, results in bonds of consistently high initial shear strength (table 4). An indepth study of both bond strength and durability is underway to further quantify and substantiate the effect of press drying surface temperature and time.

[4]Appreciation is expressed to the Coe Mfg. Co. for use of their experimental jet dryer at Painesville, Ohio.

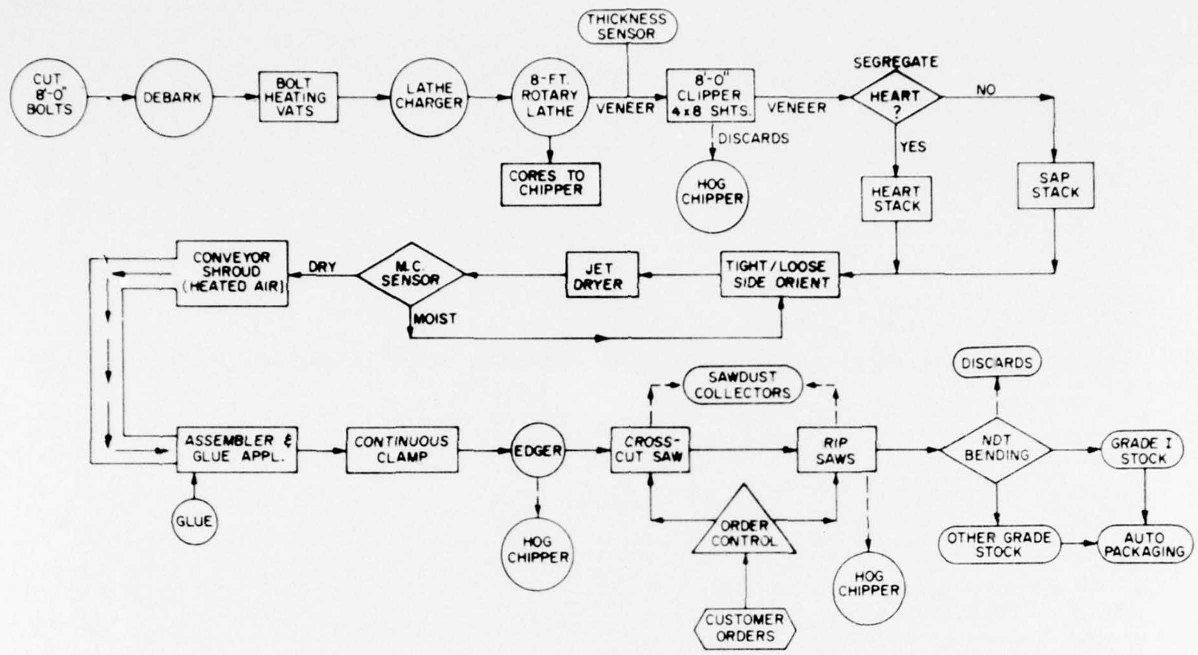

Figure 5.--Possible Press-Lam processing system incorporating a jet dryer.
(M 140 583)

Adhesive economy

Adhesive cost is 30¢/lb and about 39 pct of production cost at present (9). Because adhesive cost is so important, continuing attention must be paid to assessing suitable adhesives that are economical or to making changes in processing so less adhesive is used.

The room-temperature-curing phenol-resorcinol previously employed (7) continued to perform excellently as a laminating adhesive. Its cost was estimated (1976) at 46 cents per pound (tank car lots) and was single spread at a rate of 60 pounds per 1,000 square feet of glueline.

Another commercial adhesive examined, and found to be compatible with the stored heat of drying adhesive cure, has an estimated cost of 24 cents per pound! This modified phenolic appears to have the lowest cost compatible with processing and desired performance.

Improved end joints

The finger joint is a potential means of producing a structural joint between the ends of abutting plies (fig. 6). Finger joints were cut in both dry and green veneer and then dried and assembled to produce joints. The residual heat of drying was also used to cure finger joints when the joint was placed between two other heated laminae or surrounded by material, which reduces heat loss at the joint.

Ideally, to obtain the best finger joints in rotary-cut veneer, the veneer should be straight grained. (When joints were cut at an angle to the grain or in cross-grained locations, the result was a very rough joint with entire fingers sometimes missing.)

Even though joints were assembled without end pressure, specimens were produced with some strength (1,800 to 9,700 lb/in.^{2}). This is, of course, significant as compared to unbonded butt joints. Wood failure was nonexistent or very low. With end pressure, finger joints of excellent strength could probably be consistently attained.

If a finger joint is desirable in some Press-Lam products, further work is required to establish a means of incorporating such a joint in the processing.

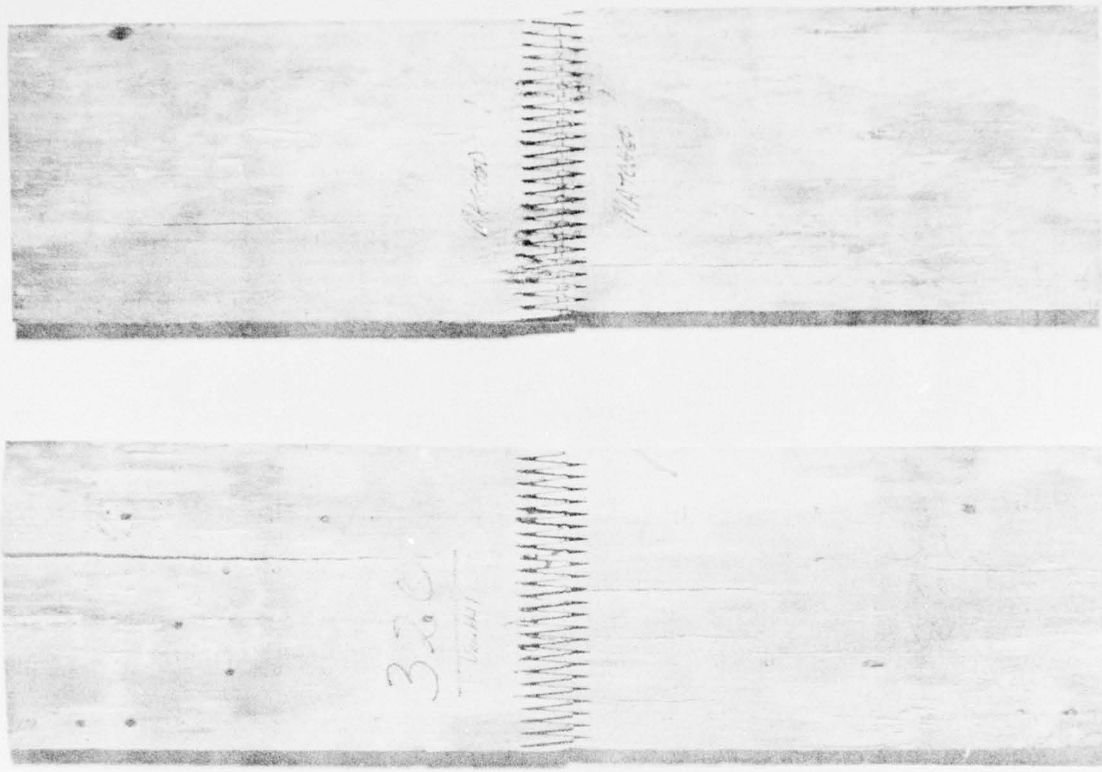

Figure 6.--Finger joints ready for gluing in thick rotary-cut veneer.
(M 139 130)

PRODUCTS CONSIDERED

Structural lumber

Strength and Stiffness

The strength evaluations were largely designed to examine whether low-quality softwood logs could produce a structural material with properties comparable to those of a grade of solid-sawn structural lumber. Lowest sawlog grade southern pine (grade 3 (*24*)) and Coast Douglas-fir (PNW grade 4) provided the bulk of the raw material. A typical bolt from a grade 4 Douglas-fir log is shown (fig. 7) and a four-ply layup with veneer from such a bolt (fig. 8). The specimen types and numbers are given in table 5, with measured mechanical properties in table 6.

Edgewise Bending

Six-ply Press-Lam vertically laminated bending members made from grade 3 southern pine logs resulted in a product containing many 2-1/2-in.-diameter knots in 4-1/2-in. deep specimens. Despite these large knots, 15 specimens had bending strengths similiar to those required of No. 1D southern pine lumber. The average stiffness of effective modulus of elasticity (MOE) was about equal to that of the Nos. 2 and 3 structural southern pine.

An analysis of the bending strength for 90 vertically laminated joists produced from PNW grade 4 Coast Douglas-fir logs or 50 pct PNW grade 4 and 50 pct PNW grade 1 logs resulted in structural sawn grade equivalences shown in table 7.

Mixing veneers from grade 1 and grade 4 logs (50:50) to produce Press-Lam improved the strength of four-ply members by 23 pct over that of all veneer from grade 4 logs. Results reported do not provide a reliable basis for

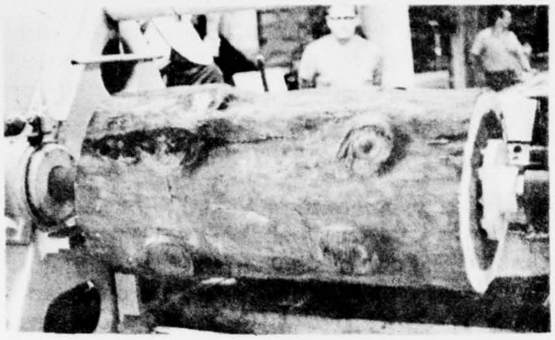

Figure 7.--Bolt from grade 4 Coast Douglas-fir log ready for rotary cutting.
(M 140 442-3)

setting design stresses, but show that even extremely poor-quality sawlogs can be converted by the Press-Lam process into members able to qualify as stress-rated lumber.

These data reinforce the findings (*7*) that the Press-Lam process improves the minimum strength by one grade and may produce a stiffness comparable with sawn lumber from similar logs. Koch (*13*) reports a similar improvement.

Flatwise Bending

Six-ply Press-Lam was produced from grade 4 Coast Douglas-fir logs and tested in flatwise bending. As can be expected, the butt joint in outer plies was a severe strength-reducing factor. Data from 15 specimens (table 6) indicated that a six-ply product from low-grade logs would qualify for the lowest structural class strengthwise and be below that in stiffness.

Tensile Strength

Six-ply Press-Lam produced from grade 4 Coast Douglas-fir logs was tested in tension. Data from 15 specimens indicated a No. 2 structural equivalency in strength (table 7). However, the stiffness of these members is unusually high and one should be cautious in interpreting the results. Bohlen (*5*) found that similar six-ply laminated veneer lumber from grade 2 Coast Douglas-fir logs had strength and stiffness equalling or exceeding published allowable values in Select Structural grade of solid-sawn lumber.

Effective Modulus of Elasticity

The joist-type specimens were vibrated flatwise prior to destructive tests, and vibrational MOE values obtained. These values

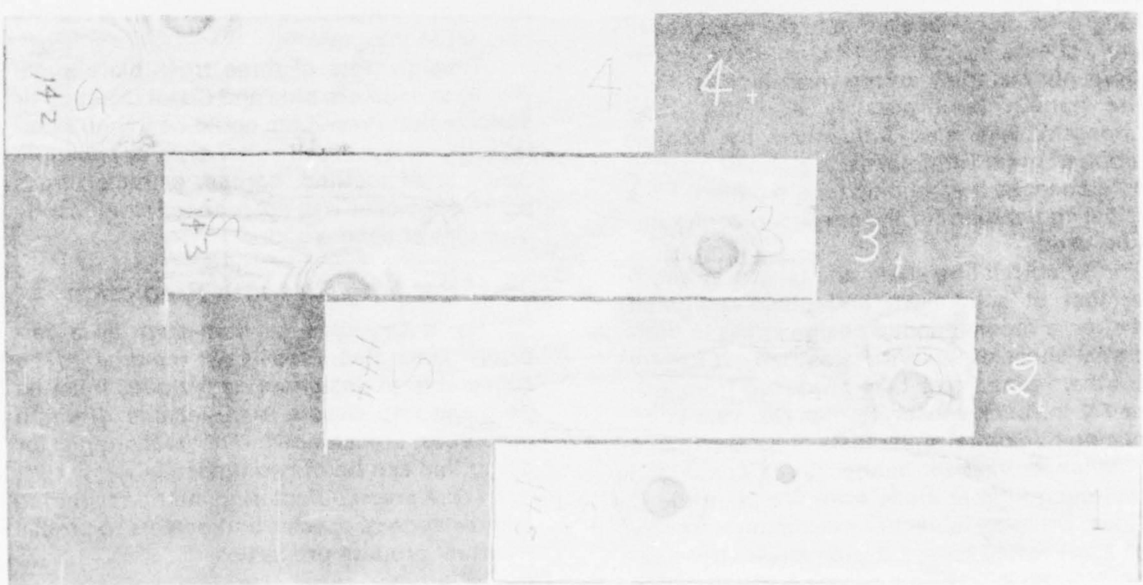

Figure 8.--Open assembly of thick veneer from grade 4 Douglas-fir log for four-ply joist.
(M 140 452-9)

were compared with the static effective MOE for each group (table 8). The average vibrational MOE was consistently about 10 pct higher than static MOE. Thus, the vibration technique appears useful for rapid prediciton of static MOE for Press-Lam.

Shear and Fatigue Strength

An inconsistency in horizontal shear strength between small clear specimens (*19*) and structural size Press-Lam lumber led to an evaluation of differences. One factor expected to influence shear strength was the relative slope-of-grain difference between plies. This was evaluated in full-size Press-Lam lumber in which slope of grain in the veneer plies was varied between straight-grained and 1:14.

In addition, fatigue resistance of Press-Lam was explored to determine its resistance to repeated loading. Load was oscillated between 60 and 6 pct of maximum. This was considered important because previous FPL work (*16*) indicated that checks in regions highly stressed in horizontal shear have a more severe effect on fatigue than on static strength.

A total of 40 static and 28 fatigue tests were conducted with the results summarized in tables 9 and 10.

Vertically laminated southern pine Press-Lam material was lower in horizontal shear strength than solid sawn under both static and fatigue loadings--likely due to the presence of lathe checks induced in 0.413-in.-thick veneer (four-ply material) during manufacture. Failure pattern (and possibly also the shear strength) was also influenced by relative slope of grain within plies. A slope of grain of 1:14 changes the bending failure pattern from shear to bending for the specimen configuration used.

By correlating shear and fatigue strength to that of solid-sawn and glued-laminated timber, a recommended design stress in horizontal shear of 90 $lb/in.^2$ was derived for dry southern pine Press-Lam produced from 3/8- or 1/2-in.-thick veneer. Bohlen (*6*), after completing horizontal shear tests of 2×8 sections of laminated-veneer-lumber (LVL), concluded that such lumber made from 1/4-in. grade C Coast Douglas-fir veneer (maximum knot size of 2 in.) would have a design shear stress exceeding 95 $lb/in.^2$ This can be compared with the currently used value of 200 $lb/in.^2$ for glued-laminated timber and 95 $lb/in.^2$ for solid-sawn dimension lumber. It is possible, with additional research, that slightly higher shear stress design values could be justified for Press-Lam.

Tendency to Warp

Warp was measured in 120 four- and six-ply Press-Lam specimens of Coast Douglas-fir (table 11). Four specimens of six-ply southern pine were also added. Only the warp characteristics of bow and twist were significant, as no crook and little cup occurs in Press-Lam due to method of processing.

The warp tendency of all Press-Lam material, both shortly after processing and after various conditioning periods to produce higher average moisture contents, fell well within the limits of that allowed in the highest grade of structural lumber. Most Press-Lam material was manufactured at 10 pct average moisture content so apparently this dryness results in a stable Press-Lam product.

Fastener Strength[5]

Withdrawal and lateral loads for nails and staples in both southern pine and Coast Douglas-fir Press-Lam were considerably less than would be expected for solid wood (table 12). The lateral load resistance of fasteners in Press-Lam was probably reduced over that of solid wood due to the influence of lathe checks parallel to the grain.

Tension tests of three truss plate joints (fig. 9) in southern pine and Coast Douglas-fir indicate that Press-Lam could be joined satisfactorily in a trussed rafter-type application. Strength of toothed, barbed, or nailed truss plate assemblies was not reduced significantly over that of solid wood.

Joist Bending Strength Prediction

For a structural product such as a vertically laminated Press-Lam material to be acceptable to designers, techniques must be developed to assure that reliable strength properties are attained. The techniques for doing this can be of two types:

(1) A premanufacturing method requiring a knowledge of species and defects to predict eventual product properties.

[5]The investigations of fastener strength were carried out by T. L. Wilkinson, Engineer, at FPL.

(2) A postmanufacturing method requiring a nondestructive measure of product consistency.

Both techniques were partially evaluated for potential application to improve the reliability of Press-Lam performance and provide a basis for design criteria specification and quality control.

Premanufacture Techniques

The premanufacture approach was to record the location and magnitude of strength-degrading characteristics in plies that make up a Press-Lam member. Such strength-reducing characteristics as knot size and frequency, slope of grain, and voids in plies were photographed.

A standard slope-of-grain strength ratio taken from ASTM D 245 (*2*) was employed to account for slope-of-grain effect in a given ply. A butt joint was considered as a knot occupying the full cross section of a ply. Four different methods were tested for their ability to predict the effect of knots and the other characteristics on measured bending strength of 120 vertically laminated members of southern pine. All methods included the effect of knots and butt joints as reductions to the moment of inertia of the Press-Lam cross section.

The model most highly correlated to behavior explained only 24 pct of the variation in modulus of rupture (MOR) due to defects.

From the standpoint of efficiency, all methods examined were unsatisfactory. This indicated that either the appropriate model was not found, or that the use of visual classification of ply defects is questionable for estimating the bending strength of a vertically laminated Press-Lam product.

Postmanufacture Techniques

Numerous investigations in the past 10 years have shown that the modulus of elasticity of structural lumber can be used as an indicator of bending strength. This, along with additional visual grading, forms the basis for machine stress rated (MSR) lumber. Using the combined system, higher stresses can be justified than those by visual grading alone. In general, it has been believed that laminated materials might not adapt to such a mechanical grading system as well as sawn lumber.

Here the use of MOE alone to predict the MOR was examined for 207 Press-Lam bending specimens of either southern pine or Coast Douglas-fir (fig. 10). The equation best describing the MOR-MOE relationship was:

$$\text{MOR} = -2{,}012 + 4{,}593 \text{ MOE}$$

where the MOR is in lb/in.^{2} and MOE in million lb/in.^{2}. The correlation coefficient R was 0.91 and the standard error was 712 lb/in.^{2}.

The value of the correlation coefficient of

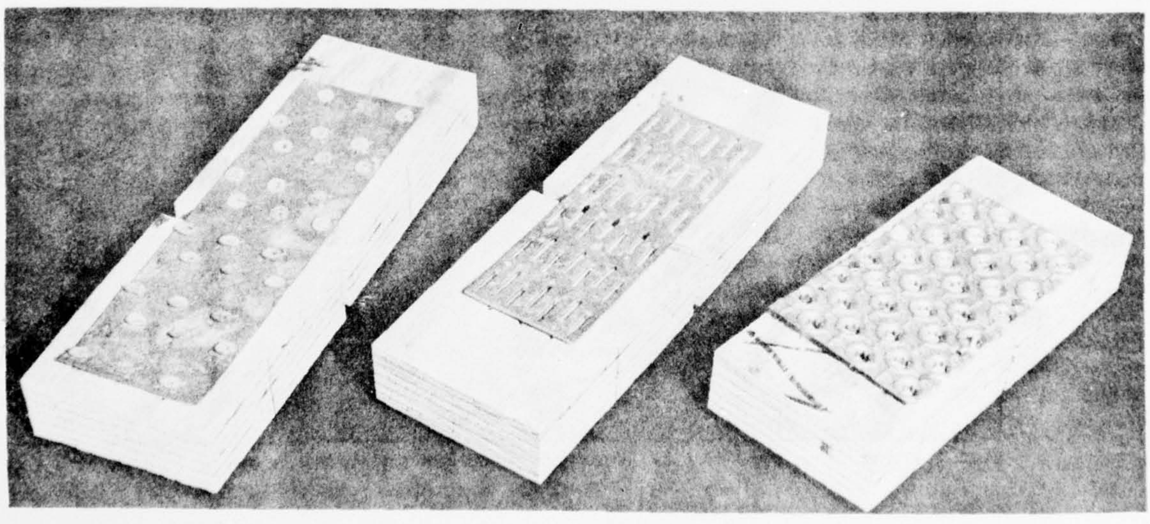

Figure 9.--Three types of metal plate connectors evaluated in Press-Lam. Left, nailed metal plate; center, toothed plate; right, barbed metal.
(M 140 587)

0.91 indicates that 82 pct of the variation in MOR could be explained by a measured average MOE. This further implies that MOE shows promise as a grading criteria for Press-Lam.

(A combination of a predictive strength model based upon defect location, specific gravity, and measured MOE did not provide significantly better correlations to strength than did MOE by itself.)

Bending Strength Grading Procedure

Press-Lam produced from PNW grade 4 Coast Douglas-fir logs alone resulted in bending members having a mean MOE less than or equal to 1.3 million lb/in.[2] independent of number of plies. Hence MOR-MOE data in figure 10 representing these Coast Douglas-fir specimens fall largely to the left of the 1.3 million lb/in.[2] MOE level.

The mean MOE was 1.44 million lb/in[2] for four-ply Press-Lam members assembled from veneer composed of 50 pct grade I and 50 pct grade 4 logs, and the MOR strength data for this group of specimens are distributed in the 1.44 million lb/in.[2] area on figure 10.

The MOR-MOE data for Press-Lam assembled from southern pine "woods run" and grade 3 sawlogs fall in the MOE area of figure 10 above 1.3 million lb/in.[2].

Obviously, quality of raw material can have a distinct effect on the strength and stiffness of Press-Lam produced from it. Controlling the raw material quality, therefore, is one way to control Press-Lam strength and stiffness.

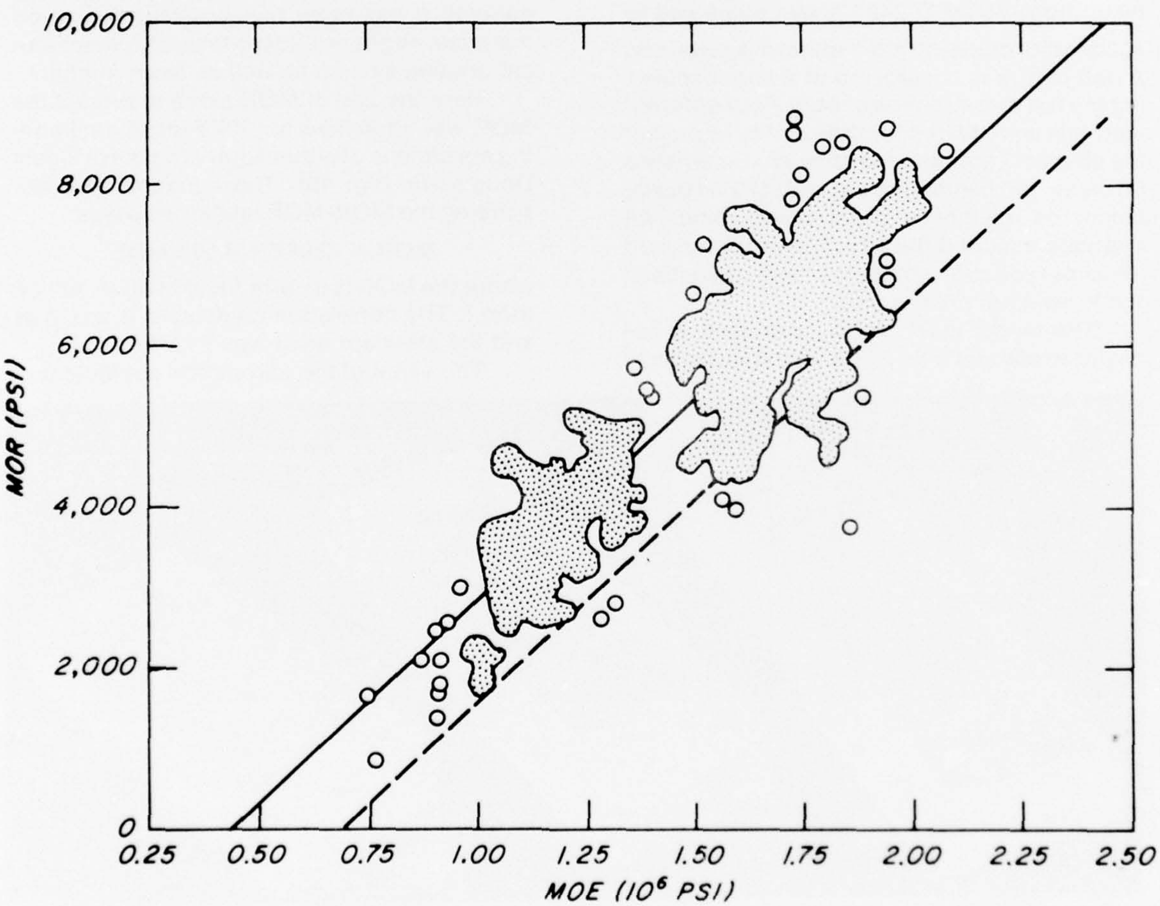

Figure 10.--Bending strength versus stiffness for softwood Press-Lam. Solid line represents regression line while dashed line is an estimate of the 0.05 percentile. Dotted areas indicate a concentration of points. (M 143 807)

The applicability of MOE as a strength predictor was compared with current MSR grading rules. A modified stepwise grading system (based upon constant MOR levels for a ±100,000 lb/in.^{2} to ±150,000 lb/in.^{2} range in MOE) was developed for Press-Lam as shown in table 13 and figure 11. The difference between the MSR system for lumber and a hypothetical system for Press-Lam is reflected in Press-Lam having higher design stresses for material stiffer than 1.6 million lb/in^2 and lower design stresses for less stiff material.

For a true test of the hypothetical grading system for Press-Lam, the applicability should be tested using samples different from those used in its development.

Large members and panels

Strength and Stiffness

Three large vertically laminated beams and two panels were manufactured using reheated 0.46-in. dry rotary-cut veneer from ten 4-ft bolts from Coast Douglas-fir PNW grade 4 logs. The dimensions of these beams and panels are shown in table 14. Low-quality input material was deliberately chosen to demonstrate that the Press-Lam process can furnish acceptable structural members from almost any grade of input.

The beams were tested to failure in two-point bending with a center span of 9.5 ft and

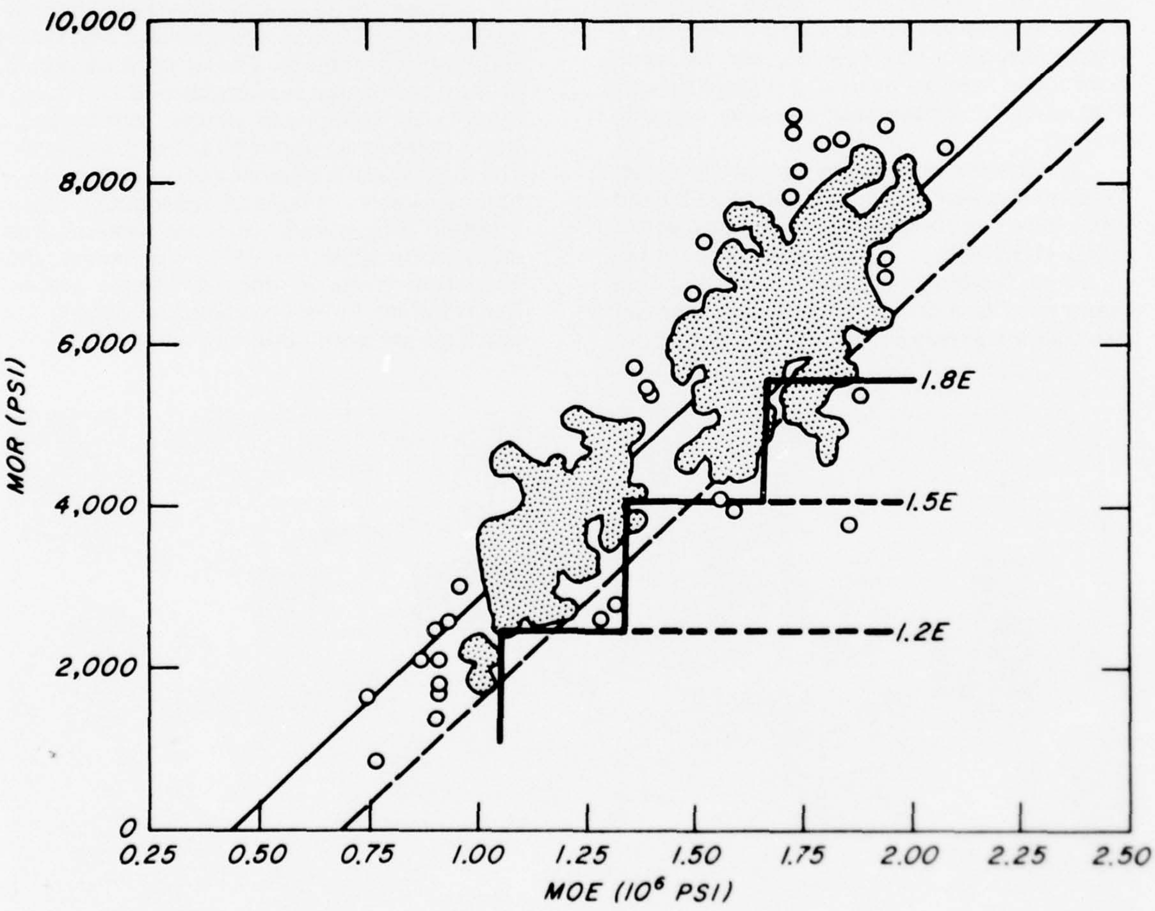

Figure 11.--Grading system for Press-Lam using a stiffness-strength relationship. For simplification, three grade levels corresponding to different stiffnesses have been estimated based on Coast Douglas-fir and southern pine. (M 143 806)

total span of 19 ft (fig. 12). Panels were tested with short edges simply supported over a 6-ft span, long edges free, and corners clamped (fig. 13). A single center load was applied over a 20- by 15-in. area (double tire print).

By directly testing lowest raw material input in Douglas-fir Press-Lam beams, insight was obtained into the near-minimum design stress attainable for mill-run Press-Lam beams of this size and of low-grade material as input. The strength measured was used to estimate an approximate design strength for such beams of 1,500 lb/in.^{2}; the effective MOE averaged 1.38 million lb/in.^{2}. Hence the expected strength is equivalent to beam and stringer No. 1 Douglas-fir (1,550 lb/in.^{2}), and stiffness is about 14 pct below that of the same grade. If these same logs had been sawn into lumber, the predominant grade has been shown by others to be No. 3 for 2-in. structural lumber. Larger timbers would not be sawn from these logs because of the large defects that severely reduce load-carrying capacity (*11, 18*).

The panels sucessfully withstood direct bending stresses of approximately 3,600 and 4,600 lb/in.^{2} as compared to the beams, which failed at 3,200 lb/in.^{2} The panels did not fail in direct bending, however, indicating that many plies in a vertically laminated member can tolerate severe defects in individual plies. A comparison of the Press-Lam panel performance with that required for timber bridges (*1, 17*) showed that Press-Lam panels meet the specification.

The strength tests indicate that Douglas-fir Press-Lam is a promising material for timber bridge stringers and decks even when produced from low-grade logs.

Treatability and Fire Resistance

The treatability of Press-Lam in large sections was excellent even in a difficult-to-treat species such as the heartwood of Coast Douglas-fir. This treatability enhances the use of Press-Lam in exterior applications where decay is an ever-present problem for wood members.

Sections of Press-Lam, 6 by 12 in. in cross section and 10 ft long, were treated with creosote by three methods. The sections consisted of mixed sapwood and heartwood of 1/2-in.-thick Coast Douglas-fir veneer, with the sapwood comprising about 20 pct of the volume. The methods of treatment and achieved retentions are shown in table 15. Distribution of the creosote throughout the cross sections was attained by lathe checks in the veneer and open butt joints at ends of veneer sheets. Retention could be controlled by varying the initial air pressure upon beginning treatment.

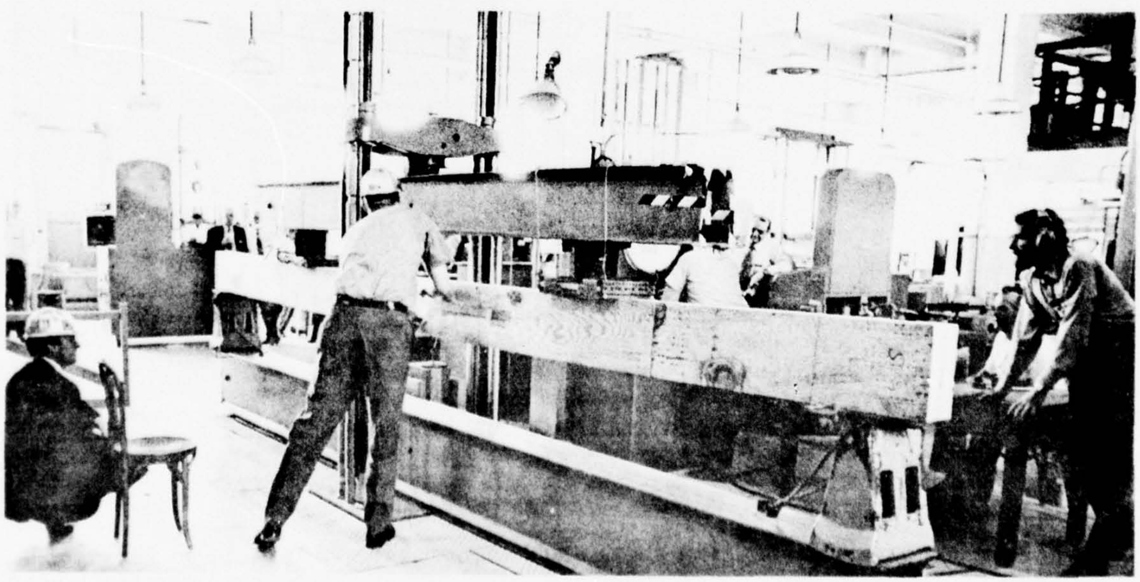

Figure 12. -- Test of Press-Lam bridge stringer. (M 140 153-5)

A typical section treated to 7.7 pounds per cubic foot (lb/ft^3) (lowest retention) is shown in figure 14. Additional information is available on treatability in (*25*).

Thick plates were produced from the beams made for strength tests, and exposed to ASTM E 119 (*3*) standard fire conditions on one surface. Both normal-to-the-grain directions were evaluated in replicate specimens. Measurements of char progression with time and comparison with previous work (*21*) showed no increase in the rate of charring for Press-Lam as compared to solid-sawn material.

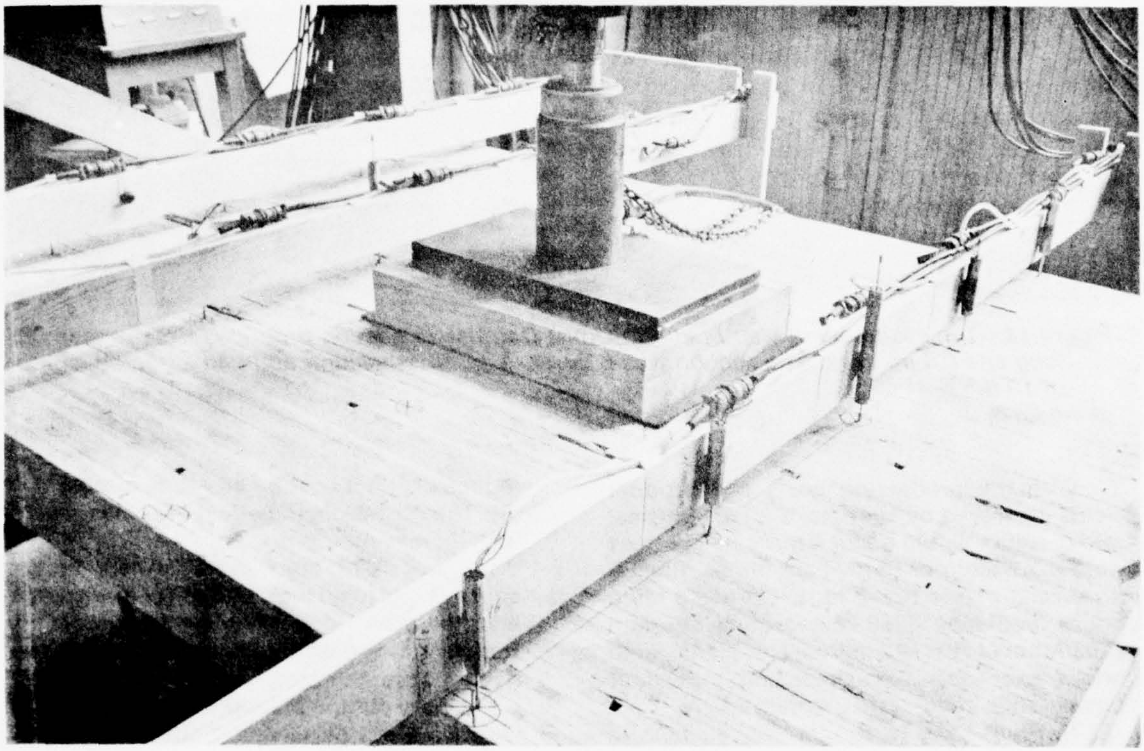

Figure 13.--Vertically laminated Press-Lam bridge deck panel in test.
(M 140 281)

PRESS-LAM ECONOMICS

Harpole (*9*) made a comprehensive analysis of likely profitability of manufacturing joists and other dimension materials by Press-Lam processes. He estimated 1975 manufacturing cost (excluding log cost) for Press-Lam lumber of 1/4-inch veneer to be about $109/Mbm (Scribner log scale) or $1.93/ft^3 of product (table 16). The comparable cost of manufacturing sawn lumber was estimated to be about $52.90/Mbm or 93 cents/ft^3 of solid wood output. (Similar manufacturing cost estimates were $1.36/ft^3 of particleboard, $1.59 for flakeboard, and $1.40 for plywood.)

The analysis assumed a hypothetical $10 million Press-Lam mill designed to produce 60 MMbm of product annually. (Equivalent sizes of facilities for lumber were $4.6 million; particleboard $18.7 million; flakeboard $15.6 million; and plywood $15.9 million.) The hypothetical Press-Lam facility would have included two 4- by 60-ft continuous cold presses[6] assumed to cost $2.5 million each.

[6]Since this report was written, such presses have reportedly become available from Trus Joist Corporation of Boise, Idaho, and Eduard Kusters Maschinenfabrik of Krefeld, Germany.

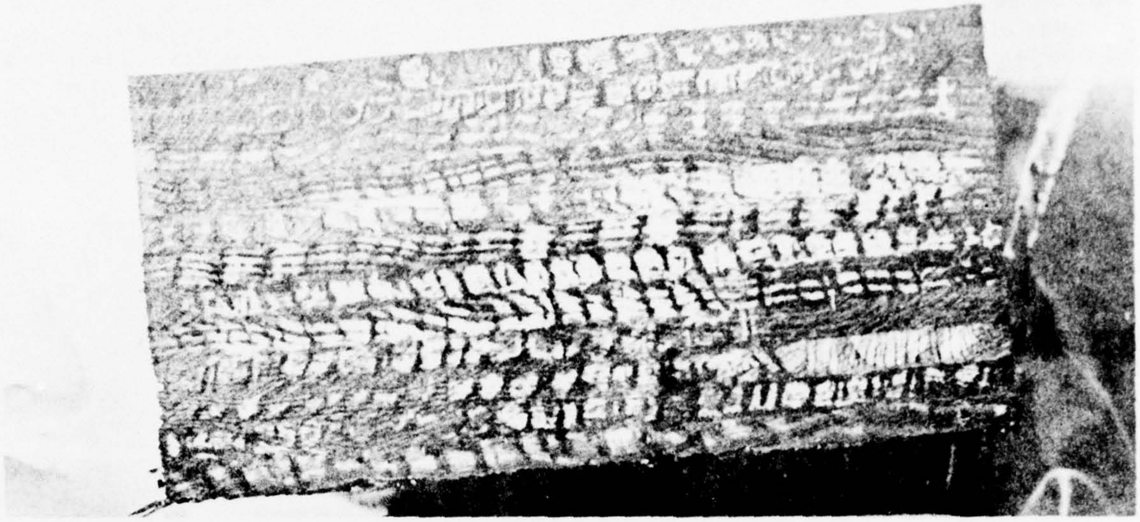

Figure 14.--Typical creosote distribution in Coast Douglas-fir section produced from veneer 4 ft long and 0.5 in. thick. The section was 6 by 12 in. in cross section and had a treated length of 10 ft.
(M 140 497-5)

With the processing costs and product yields estimated by Harpole, a 20 pct internal rate of return would occur if mill selling prices were $241/Mbm of Press-Lam from Douglas-fir special peeler No. 2 logs. Corresponding prices would be $228 for sawmill logs and $203/Mbm of Press-Lam from No. 3 logs. Such prices exceeded average selling prices for comparable, solid-sawn lumber in 1975.

If Press-Lam is to develop successful markets, processing costs must be lowered or higher value products must be produced.

Reducing production cost

Improvements in several areas of processing could lower product costs (that includes log costs), but some of the more likely avenues are:

--Further increases in yields from rotary-cut bolts
--Increased production rates without proportionate increases in capital cost
--Decreased adhesive costs

Yield

Product yield significantly affects final product cost. With No. 3 sawlogs costing $125/Mbm a 5 pct improvement in yield would reduce product cost by $6/Mbm, lumber tally (9). The cost-reducing effect becomes greater with increasing log prices.

Spin-out of bolts during rotary cutting causes bolts to go into "chips" (or sawn studs) and therefore influences product recovery. Hence, chuck design to minimize spin-out is a needed research area.

Rotary cutting of bolts to cores of 4 in. can improve yield of veneer. Bolts are normally rotary cut to 6-1/2 in.-diameter cores, but chucks are available to cut to 4-in. cores. Whether veneer thicknesses of 1/4 in. can be continuously rotary cut in this manner is unknown. On bolts 15 in. in diameter, veneer yield increases about 10 pct with a decrease in core diameter from 6.5 in. to 4 in. The technical aspects of peeling thick veneer from small cores requires investigation.

Production Rates

Increased production rate, without commensurate increases in equipment and other processing costs, would obviously reduce product cost. Harpole (9) estimated that a 5 MMbm/yr increase in production would reduce product cost 4 pct. A likely means of achieving this would be to employ higher veneer dryer temperatures and a faster setting

adhesive so that shorter clamp times are possible. This would require extrusion of the adhesive onto the panels at the infeed end of the continuous cold clamp to prevent adhesive precure.

Decreased Adhesive Cost or Use

The phenol-resorcinol adhesive represents about 39 pct of Press-Lam (6 ply) manufacturing costs (9). A decrease in this cost would influence product cost greatly. In his economic analysis, Harpole assumed the adhesive, priced at 30 cents/lb of solids, was spread at the rate of 60 lb/1,000 ft^2 of glueline in six-ply Press-Lam 2X dimension. A decrease of 10 cents/lb in glue would bring an 8 pct decrease in production cost.

Higher performance or specialty structural product

A high product price would logically enhance the profitability of Press-Lam. High prices might be obtained by improving Press-Lam processes to yield higher strength materials or by producing specialty products, such as crossarms and railroad crossties. Railroad crossties sold for as much as $18 per tie ($300/Mbm) in 1975. A price of $300/Mbm would not be too much to pay for specialty structural products such as truss lumber and crossarms.

Truss lumber would be attractive if available in long lengths and of reliably high tensile strength and stiffness. To attain maximum strength and stiffness, Press-Lam could be made with higher quality peeler bolts as input material (5).

Shorter products, as crossarms and railroad crossties, can be batch-produced using several single-opening presses. The feasibility of batch-producing crossties is currently under investigation at FPL. Demonstration of Press-Lam crossarm and truss lumber technology is needed.

For the investor, a plant flexible enough to produce many different kinds and grades of Press-Lam products might be the best answer. But further data on cost and prices of alternative products would be needed to evaluate this possibility.

CONCLUSIONS

This report illustrates both encouraging and limiting aspects of Press-Lam processing for structural lumber-type products.

Estimated yield of structural product from logs between 12- and 28-in. diameters continues to appear to be between 56 and 66 percent. Large-scale yield studies are required to ascertain whether mill-run recoveries will be of this order.

Some means of providing processing flexibility proved acceptable. These included reheating of previously dried veneer, drying veneer using a jet roller veneer drying instead of press-drying, increasing temperature of drying, and incorporating finger joints between abutting plies. A jet dryer provided about 10 pct faster drying than roller veneer, but press-drying was twice as fast. Though higher temperature press-drying of veneer (about 375° F) was not deleterious to bond quality, work in the literature on reheat-laminating requires one to be cautious in acceptance of these positive results. Further study is underway.

Producing structural lumber by the Press-Lam process shows that even extremely poor quality sawlogs can qualify as stress-rated lumber. Vibration MOE of the product was about 10 pct higher than that statically derived. A slope-of-grain of 1:14 in constituent veneer can change bending failure from shear to bending in 10:1 span-to-depth ratios.

A design horizontal shear of 90 lb/in^2 was derived for southern pine Press-Lam and higher levels may be possible. Warp tendency was within the limits of that allowed for the Select Structural lumber.

The lateral and withdrawal loads for nails and fasteners in Press-Lam were considerably below that of solid wood, but truss plate joints performed very well.

Predicting the strength of Press-Lam using stiffness was very promising. The correlation between strength and stiffness for the 200-specimen sample was very high. Hence, a grading criterion using stiffness is feasible.

Using low-grade logs to produce Press-Lam of 2-to-3-inch thickness and further lami-

nating can produce structural grade timbers. Panels produced in a similar fashion can meet specifications of panels for timber bridges. In addition, treatability is excellent and easily controlled. Fire resistance compares favorably with that of solid wood.

Current cost estimates for producing Press-Lam lumber indicate that it would not be attractive for producing a high-volume structural lumber (e.g. No. 2 joists). The economics favors a higher performing product. Critical in providing Press-Lam at reasonable cost is the high production rate achieved with a continuous cold clamp. Such presses are reportedly available now.

RECOMMENDATIONS

The feasibility of processing and obtaining a reliable structural lumber product continues to be positive. Obviously the cost and profitability of producing Press-Lam are critical in its development and marketing. This section covers further research needs in processing and development of structural products, and performance attributes as influenced by process economy.

Product yield

Product yield estimates of Press-Lam consistently promise that 60 pct by volume of the logs employed could be converted to laminated veneer products. Recovery of lumber from peeler cores improves total yield of lumber type product another 5 pct. Because the cost of converting quality logs to Press-Lam is significantly affected by product yield, a large-scale product yield study should be undertaken to verify yield estimates. The best practices now available should be employed.

As previously mentioned, "spin-out" of bolts during rotary cutting results in the bolt being sawn into studs or "chipped." An understanding of the factors affecting spin-out is not reflected in the available literature, hence corrective measures are not clear. Research on the fundamental factors influencing spin-out of bolts is recommended.

A 10 pct improvement in veneer yield can result for peeling 15-in. bolts to 4-in. cores instead of a more conventional 6.5-in. core. Achieving smaller cores while peeling thick veneer appears especially difficult because of the likelihood of spin-out. How to peel thick veneer from bolts to 4-in. cores needs investigation.

Adhesive

The adhesive constitutes about 39 pct of the cost to produce 6-ply Press-Lam at present (*9*). Another modified phenolic adhesive found promising is about half the cost of a glue laminating adhesive (phenol-resorcinol), but greater than a plywood adhesive (phenol-formaldehyde). Ways should be sought to reduce the influence of adhesive cost on production cost, yet retain acceptable performance. Recommended areas for investigation include optimization of gluespread rate and further modifications in adhesive formulation.

Higher performance products

The economic analysis (*9*) indicates a higher performance structural product is desirable to provide attractive rates of return on sales. One way of influencing performance now concerns the unbonded joints between veneer ends in staggered plies. A more homogeneous product, produced by including a joint, appears to be the most effective means to increasing strength, stiffness, and uniformity. Processing research is recommended to include a finger joint, or other effective joint, between ends of veneer in each ply.

Grading and quality control

Nondestructive measurements of the stiffness of Press-Lam lumber may be the key both to process control and product quality. The performance of Press-Lam can be traced back to quality of the log and veneer used in

processing. It is recommended that (1) further effort be applied in testing the quality control and strength correlations of nondestructively measured stiffness and (2) that the links between log-veneer quality and Press-Lam quality be quantified. Both recommendations are to develop technology that could make Press-Lam processing control and use adaptable by industry.

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Table 1. -- Cubic volume[1] of veneer, residuals, and losses from heated and unheated blocks of two grades of Douglas-fir (*8*)

Item	No. 2 peelers				Special mill logs			
	Unheated		Heated		Unheated		Heated	
	Ft³	Pct	Ft³	Pct	Ft³	Pct	Ft³	Pct
Veneer	82.95	56.7	81.21	55.7	74.92	53.1	77.75	54.1
Residuals:								
Panel trim[2]	12.93	8.8	12.66	8.7	11.67	8.3	12.12	8.4
Sanding and compression[3]	9.22	6.3	9.02	6.2	8.32	5.9	8.64	6.0
6-in. cores	5.46	3.7	3.66	2.5	8.20	5.8	8.01	5.6
Split cores[4]	.81	.6	4.17	2.9	--	--	--	--
Spur trim	3.97	2.7	4.00	2.7	3.90	2.8	3.56	2.5
Roundup, clippings:[5]								
8-ft lathe	15.77	10.8	16.43	11.3	19.97	14.2	18.97	13.2
4-ft lathe	4.25	2.9	4.04	2.7	4.16	2.9	4.47	3.1
Shrinkage loss:[6]								
1/10-in. veneer	10.10	6.9	10.06	6.9	9.19	6.5	9.56	6.6
3/16-in. veneer	.84	.6	.64	.4	.68	.5	.68	.5
Total veneer block input[7]	146.30	100.0	145.88	100.0	141.01	100.0	143.76	100.0

[1]Based on each Mbm of logs, net log scale.

[2]Estimated as 12.3 pct of dried, untrimmed veneer.

[3]Sanding and compression loss estimated as 10 pct (*7*).

[4]Volume of cores rejected at main lathe as unpeelable.

[5]Included in this category in addition to block rounding and undried clipping residuals are dry clippings; small split pieces of veneer; veneer lost in dryer; veneer rejected at glue spreader; and any other small inadvertent losses.

[6]Veneer, panel trim, and sanding and compression volumes are based on volume at 6 pct moisture content. Other volumes are based on volume as received.

[7]Based on actual measurements of veneer blocks and net block scale.

Table 2.--Estimated ratio of cubic volume recovery for dry finished products from woods-length old-growth Douglas-fir logs [1,2] (*10*)

Log grade	Lumber	Plywood	FPL Press-Lam products		
			Best[3]	Low	High
	Pct	Pct	Pct	Pct	Pct
Special peeler	49.7	55.5 (50.6)	65.9 (60.9)	61.8 (56.8)	72.4 (67.4)
No. 2 sawmill	52.0	54.2 (50.7)	64.7 (60.1)	58.8 (54.2)	71.2 (66.6)
No.3 sawmill	48.7	46.6 (42.9)	56.3 (50.4)	52.9 (47.0)	62.2 (56.3)

[1]Derived from U.S. Forest Service product recovery studies (*14, 15*).

[2]Values in parentheses are volumes that exclude estimates of sawed lumber recoverable from peeler cores.

[3]Best estimate, with low and high values.

Table 3.--Strength and wood failure of Douglas-fir Press-Lam made with two drying methods and four methods of heating

Laminating method	Strength at moisture content of			Wood failure at moisture content of		
	5 pct	10 pct	20 pct	5 pct	10 pct	20 pct
	Lb/in.^{2}	Lb/in.^{2}	Lb/in.^{2}	Pct	Pct	Pct
Press drying						
Assembled immediately[1]	2,130	2,130	1,780	97	96	94
Cooled and reheated in:						
Chamber at 200° F	1,915	2,075	1,835	99	94	96
Press dryer	1,860	2,025	1,610	94	98	97
Roller veneer dryer	2,030	1,980	805	98	95	35
Roller veneer drying						
Assembled immediately[1]	2,000	1,640	1,530	99	96	98
Cooled and reheated in:						
Chamber at 200° F	1,810	2,095	1,675	98	94	92
Press dryer	2,120	1,890	1,520	98	97	98
Roller veneer dryer	2,185	2,260	1,940	97	97	98

[1]After drying, using residual heat of drying.

Table 4.--Effects of block shear specimen size, platen temperature, and moisture content on shear stress[1]

Moisture content	Platen temperature, °F					
	375	400	425	450	475	500
	STANDARD 1- BY 1-IN. SPECIMENS					
6	1,541	2,527	1,706	2,154	2,037	1,820
12	1,968	2,449	2,587	2,174	2,363	2,099
Average	1,754	2,488	2,146	2,164	2,200	1,959
	MODIFIED 1-1/2- BY 2-IN. SPECIMENS					
6	1,343	1,638	1,170	1,393	1,411	1,247
12	1,342	1,584	1,709	1,618	1,297	1,225
Average	1,342	1,611	1,439	1,505	1,354	1,236
	ALL SPECIMEN MEANS					
Average 6	1,442	2,082	1,438	1,773	1,724	1,533
Average 12	1,655	2,016	2,148	1,896	1,830	1,662
Grand average	1,548	2,049	1,793	1,835	1,777	1,598

[1]Values shown are average shear stress results in pounds per square inch.

Table 5.--Experimental design showing specimen types

Group identification	Specimen[1] cross section	Pacific Northwest log grade	Number of plies	Sample size	Type of test	Span length	Total length
	In.					Ft	Ft
G	4.5	4	4	[2]30	Edge bend	7.5	8
I	4.5	4	6	21	...do...	7.5	8
J	4.5	4	6	21	Flat bend	7.5	8
K	4.5	4	6	15	Tension	[3]6	12
L	9.5	50 pct grade 1, 50 pct grade 4	4	15	Edge bend	15	16

[1]All members were 1.5 in. by dimension shown.

[2]14 out of 30 specimens were rejected for poor glue bonds due to manufacturing difficulties.

[3]Tension specimens were 8 ft between grips; deflections were measured over a 6-ft gage length.

Table 6. -- Statistical analysis of data for each group

Group	Sample size	Moisture content		Specific gravity of wood		Modulus of rupture		Estimated 5 percent exclusion limit	Static modulus of elasticity		Vibrational modulus of elasticity	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation		Mean	Standard deviation	Mean	Standard deviation
		Pct	Pct			Lb/in.^{2}	Lb/in.^{2}	Lb/in.^{2}	Million lb/in.^{2}	Million lb/in.^{2}	Million lb/in.^{2}	Million lb/in.^{2}
G[1]	[1]16	10.6	1.6	0.45	0.09	3,510	530	2,580	1.14	0.05	1.26	0.08
I	21	10.2	2.0	.44	.02	3,960	780	2,620	1.16	.11	1.29	.09
J	21	10.6	1.2	.45	.01	2,770	650	1,650	1.03	.15	1.32	.09
K	15	11.3	1.1	.48	.02	[2]2,760	[2]390	[2]2,080	[3]1.47	[3].15	1.66	.15
L	15	11.1	1.3	.44	.03	4,190	470	3,370	1.44	.17	1.58	.22

[1]Specimens 7 to 20 omitted from sample of size 30, table 5.

[2]Tensile strength, in lb/in.^{2}

[3]Tensile modulus of elasticity in million lb/in.^{2}

Table 7--Edgewise bending properties of southern pine and Douglas-fir Press-Lam

Species	Number of plies	Log grade rotary cut	Number of specimens	Structural grade equivalence	
				MOR	MOE
Southern pine	6	3	15	No. 1D	No. 2 and No. 3
Douglas-fir	4 and 6	4	75	No. 2 or No. 3	Less than No. 3
Do....	4	1 (50 pct) 4 (50 pct)	15	No. 2 or No. 1	No. 3

Table 8.--Comparison of average vibrational and static modulus of elasticity measurements (unadjusted for specific gravity)

Group	Vibrational MOE	Static MOE		Difference[1]
		Edgewise bending	Tension	
	Million lb/in.^{2}	Million lb/in.^{2}	Million lb/in.^{2}	Pct
G	1.26	1.14	--	10.2
I	1.29	1.16	--	11.2
K	1.66	--	1.47	13.0
L	1.58	1.44	--	9.6

[1](Vibrational MOE - static MOE) × 100 ÷ static MOE.

Table 9. -- Average results of static bending tests on FPL Press-Lam and solid-sawn southern pine material[1]

Group designation	Description of material[2]	Modulus of rupture		Modulus of elasticity		Calculated shear stress at failure		Predominant type of failure
		Average	COV[3]	Average	COV[3]	Average	COV[3]	
		Lb/in.^{2}	Pct	Million lb/in.^{2}	Pct	Lb/in.^{2}	Pct	
				FPL PRESS-LAM				
I	4 plies of straight-grained 3/8-in. veneer	(7,410)	--	1.70	8.2	569	8.5	Horizontal shear
II	4 plies of 1:28 SOG, 3/8-in. veneer	(7,660)	--	1.77	11.0	587	7.7	Do.
III	4 plies of 1:14 SOG, 3/8-in. veneer	7,520	8.5	1.66	12.6	(576)	--	Cross-grain tension
IV	3 plies of mill-run, 1/2-in. veneer[4]	(7,270)	--	1.60	9.4	560	15.5	Horizontal shear
				SOLID SAWN DATA FROM FPL REPORT NO. 2236 (*16*)				
	Solid sawn, straight grained	13,540	14.4			(1,040)	--	Compression, tension
	Solid sawn, 1:12 SOG	10,150	14.5			(780)	--	Cross-grain tension
	Solid sawn, 50 pct checked	(11,500)	--			885	9.5	Horizontal shear

[1]Averages for FPL Press-Lam material based on 10 tests, for solid sawn on 14 or 15 tests. All specimens were near 12 pct moisture content. Figures in parentheses represent failure mode different than column heading would indicate.

[2]SOG = slope of grain.

[3]COV = coefficient of variation.

[4]Green thickness of plies was 1/2 in.; actual dry thickness of plies was slightly less than 1/2 in. due to shrinkage.

Table 10. -- Fatigue bending tests on four-ply Press-Lam material with plies having various slope of grain[1]

Slope of grain	Number of specimens	Mean specific gravity	Average maximum repeated stress			Cycles to failure[2]	Failure type
			Percent of static	Bending	Shear		
				Lb/in.^{2}	Lb/in.^{2}		
Straight-grained	6	0.56	60	4,450	342	176,000 (49,400-458,900)	Horizontal shear
1:28	6	.56	60	4,600	353	561,200 (208,200-1,301,300)	Cross-grain tension and shear
1:14	[3]5	.56	60	4,510	346	2,694,900 (840,700-5,066,900)	Do.
"Mill-run"	[4]3	.50	60	4,130	319	891,500 (758,400-1,309,000)	Horizontal shear
Do..........	5	.52	50	3,680	283	[5]3,023,000 (35,900-10,000,000)	Do.

[1]Specimens 4- by 1-1/2- by 43-in. were tested in bending on 39-in. span using third-point loading.

[2]Figures in parentheses represent range in results.

[3]One additional specimen was inadvertently loaded to 72 pct of control strength. Results were rejected for this specimen.

[4]Two of five specimen results were inaccurate due to an equipment malfunction during test.

[5]Includes one specimen with 10,000,000 cycles and no failure.

Table 11. -- Warp tendency of Press-Lam joists (given in percent of "very light" warp class)

Number of specimens	Initial moisture content	Final equilibrium moisture content	Means (pct) and standard deviations (pct)		
			Twist	Bow	Cup
	Pct	Pct			
SOUTHERN PINE, SIX-PLY					
4	10	6	40 (18)	50 (12)	(1)
4	10	20	48 (27)	39 (10)	(1)
COAST DOUGLAS-FIR, SIX-PLY					
52	10	10	45 (43)	27 (16)	(1)
10	10	20	39 (37)	43 (19)	(1)
COAST DOUGLAS-FIR, FOUR-PLY					
53	10	10	14 (12)	25 (16)	(1)
8	10	20	15 (15)	37 (21)	38 (60)
15	6	6	79 (38)	14 (13)	16 (33)
15	6	20	7 (9)	22 (14)	7(19)

[1]Either not measured or negligible.

Table 12.--Fastener strength in Press-Lam as a percent of that expected in solid wood

Load and species	Nails		Staples
	Six-penny	Ten-penny	
	Pct	Pct	Pct
Withdrawal			
Southern pine	55	33	52
Coast Douglas-fir	91	54	--
Lateral			
Southern pine	61	42	52
Coast Douglas-fir	80	70	--

Table 13.--Grading rules criteria

MOE class	Current MSR rules		Grading system for Press-Lam	
	Assigned f	2.1f[1]	Proposed f	2.1f[1]
Million lb/in.^{2}	Lb/in.^{2}	Lb/in.^{2}	Lb/in.^{2}	Lb/in.^{2}
0.8	--	--	200	420
1.0	900	1,890	600	1,260
1.2	1,200	2,520	1,000	2,100
1.4	1,500	3,150	1,400	2,940
1.6	1,800	3,780	1,800	3,780
1.8	2,100	4,410	2,200	4,620
2.0	2,400	5,040	2,600	5,460

[1]Near minimum expected value.

Table 14. -- Stringer and panel specimens

Specimens	Length	Width	Depth	Ply thickness	Number of plies	Butt-joint spacing
	Ft-in.	In.	In.	In.		In.
Three beams	20-4	5.5	11.5	0.46	12	12
Two panels	7-0	56	5.25	.46	126	8

Table 15. -- Creosote preservative treatments of Coast Douglas-fir Press-Lam beams[1] of 1/2-in. thick veneer

Treatment type	Step 1	Step 2	Step 3	Step 4	Uptake
					Lb/ft³
		BEAM NO. 1			
Lowry	Air at atmospheric pressure	Creosote (190° F) at 125 lb/in.² for 7.5 h	Expansion bath at atmospheric pressure for 15 min. Temperature rise 190° to 215° F	Vacuum (27 in. of Hg) for 1 h	16.9
		BEAM NO. 2			
Rueping	Air at 70 lb/in.² (absolute) for 15 min.	Same as Beam 1	--	Same as Beam 1	10.7
		BEAM NO. 3			
Do.......	Air at 90 lb/in.² (absolute) for 15 min.	Same as Beam 1	--	Same as Beam 1	7.7

[1]Beams were 5-1/2 by 11-1/2 in., 10 ft long.

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KEYWORDS: Adhesives, product yield, bending strength, stiffness, warp tendency, processing alternatives, treatability, fire resistance.

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Table 16.--Average unit costs of manufacturing Press-Lam lumber (*9*) (annual production: 60 MMbm)

Costs	Amount
	$/Mbm output
Fixed	
Electric power (hp)	0.75
Supplies	.82
Maintenance	6.47
Utilities	.17
Taxes and insurance	5.67
Labor	25.91
Administrative and overheac	16.23
Depreciation (15-yr straight line)	11.17
Total fixed costs	67.19
Variable	
Thermosetting glue (30¢/lb)	42.19
Total manufacture costs excluding log cost	109.38
Costs per cubic foot of solid wood output	1.93